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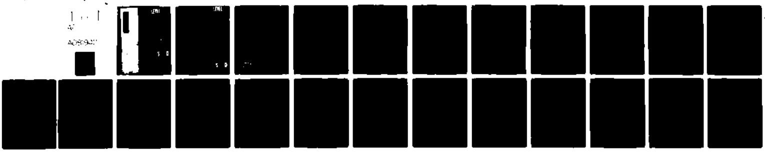

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6 **A GOAL PROGRAMMING MODEL FOR PLANNING OFFICER ACCESSIONS.**

by

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ABSTRACT

A goal programming model for planning officer accessions to the U.S. Navy from various commissioning sources is developed and described. Present and future requirements for different career specialty areas in the Navy are considered in terms of years of commissioned service and related to various "choke points" where inventories fall short of requirements in officer force structure. An illustration of the use of this model is provided which involves assessments of the effects of phasing out one commissioning source. Other uses and possible further extensions are also indicated for this model, which now forms a part of the Navy's manpower planning procedures.

KEY WORDS

U.S. Navy Officer Accessions

Warfare Communities

Officer Accession Sources

Goal Programming

Markoff Process

Network Models

Linear Programming

1. INTRODUCTION

The Navy may secure officers from a variety of commission sources which include the U.S. Naval Academy (USNA), several Naval Reserve Officer Training Corps (NROTC) Programs, etc. Officers are secured from these sources to meet requirements in a number of career specialty areas, such as surface warfare, submarine warfare, and aviation warfare, which are referred to as "warfare communities" or, more briefly, "communities."

The Navy's commissioning sources have different capacities and costs. Some sources, such as USNA, provide officers for a wide variety of communities. Others produce officers for a single community, such as aviation warfare. Since officers have shown career behavior that differs according to their commissioning source and community[1/] the choice of commissioning source mix is a major factor in the Navy's ability to meet future requirements for experienced officers. Because the Navy's manpower requirements change over time in response to major program changes, Navy planners must also be able to evaluate the match between these requirements and consequences of past and proposed accession plans, in detail, at different points in time.

The planning needs identified above provided motivation and guidance for this research which developed a mathematical model for officer accession planning that can also be adapted to the various attendant requirements for policy analysis and evaluation. Typically a sequence of examples will be solved to identify and evaluate the tradeoffs that may arise. A flexible approach is needed so that the source mix and the resulting inventory and cost (or funds flow) consequences of the various programs can be studied in a variety of different scenarios.

[1/] For a description of these officer commissioning programs and the various categories to which they apply see K. Goudreau [11] and [12].

2. APPROACH

In the model to be developed here we will describe the officer population by their number in each of a set of possible states at each time period. We will consider an officer's state to be determined by these factors: 1) warfare community, 2) commissioning program and 3) years of commissioned service (YCS). Officer inventory requirements will be specified within each community by the number needed at several experience levels. These experience levels aggregate YCS in ways that represent typical assignments within the community. Transition rates, as obtained from historical or other estimation procedures, will be used to project the on-board expected flows between states in successive time periods in Markovian fashion to which are also added new accessions into the system. It should be explicitly recognized, however, that our definition of states involves time based characteristics (YCS) and therefore differs from other (more standard) Markoff process approaches.[1/]

One of the concerns that led to development of this model was that requirements for certain critical tours were not being met, leading to "choke points" in the officer force structure. These billets, primarily at the department head level, require a level of experience that is better defined by YCS than by grade alone. Officers in most communities follow a common promotion path in their early careers and are promoted at known YCS flow points.[2/] YCS may then be used as a surrogate for grades, which need not be explicitly identified in this formulation.

[1/] Other ways of altering the Markoff property by means of constraints are described in [6] for the case in which training in one period may be used to alter career paths in periods subsequent to such training so that, in particular, the entire career paths in successive states are thereby affected.

[2/] If desired, one can add grade categories for officers not promoted in due course.

In this model we do not distinguish explicitly between regular and reserve officers although such a distinction is implicit in their commissioning sources.[1/] Again, most designator changes occur within the first several years of service and reflect a change from training to a warfare specialty service. Because we will include appropriate training designators in our warfare communities, we need not treat the lateral flows explicitly.

3. MODEL FORMULATION

The model[2/] we shall develop and discuss[3/] will utilize discrete time periods for which the following policy stipulations and parameters apply:[4/]

[1/] Explicit distinction between regular and reserve would substantially expand the model and data requirements.

[2/] Standard references on analytical approaches to manpower planning which can be consulted are Grinold and Marshall [15] and Vajda [20]. The recently published book by R.J. Niehaus [17] also deals with problems of implementation as does the earlier reference [6].

[3/] The model discussed in Grinold [14] is not adequate for the purposes to be served here. For instance, it assumes only a single personnel source rather than the multiple sources whose evaluation is critical for the problems being considered here and it has other shortcomings, including computational problems, that make its extension and adaptation for the present application unattractive.

[4/] Note that we are limiting attention to the deterministic case. In most planning problems in the Navy, "planning factors" such as strength goals, budget, and supply source availability are fixed at values which conform to standard operating procedures. Variability is present, of course, but its consequences are explored through alternate scenarios. The presence of random fluctuations as part of a manpower planning process is dealt with in Martel and Price [16]. See also Grinold and Marshall [15], and Niehaus [17]. For a treatment by "chance constrained programming," see Charnes, Cooper, Niehaus [6].

$I^o_{ij}(k)$ ≡ Initial onboard inventory of officers in community i, from source j, with YCS k.

$S^t_{ij}(k)$ ≡ Survival rate for t time periods for officers in community i, from source j, with YCS k.

$G_{im}(t)$ ≡ Strength goal for officers in community i, for experience level m, in time period t.

$E(t)$ ≡ Upper limit on total officer inventory in period t.

$B(t)$ ≡ Budget limit for officer pay and allowances, period t.

$b_{ijk}(t)$ ≡ Cost for pay and allowances for an officer in community i, from source j, with YCS k, in time period t.

$\ell_i(m)$ ≡ Lower limit for YCS in experience level m for community i.

$u_i(m)$ ≡ Upper limit for YCS in experience level m for community i.

$P(t)$ ≡ Upper limit on the total number of officers that may be commissioned in time period t.

$P_j(t)$ ≡ Maximum number of officers that can be commissioned from source j in time period t.

$Q_j(t)$ ≡ Minimum number of officers to be commissioned from source j in time period t.

$R_i(t)$ ≡ Maximum number of newly commissioned officers that can be accommodated in community i, in time t.

$P_{ij}(t)$ ≡ Maximum allowable number of officers commissioned from source j to be assigned to community i, for time period t.

$Q_{ij}(t)$ ≡ Minimum number of officers commissioned from source j to be assigned to community i, for time period t.

$w^+_{im}(t)$ ≡ Weight given to positive deviation from officer strength goal for community i, experience level m, time period t.

$w^-_{im}(t)$ ≡ Weight given to negative deviation from officer strength goal for community i, experience level m, time period t.

$w^-(t)$ ≡ Weight given to negative deviation from total officer strength limit, time period t.

I ≡ Number of communities in model.

J ≡ Number of commissioning sources in model.

K ≡ Maximum length of service in model.

M Number of experience levels in model.

Next we define the variables in our model as:

$y_{ijk}(t) \equiv$ Onboard inventory of officers in community i, from source j, with YCS k, at beginning of time period t.

$x_{ij}(t) \equiv$ Accessions to community i from source j in time period t.

$g^-_{im}(t) \equiv$ Negative goal deviation (shortfall) for community i, experience level m, in time period t.

$g^+_{im}(t) \equiv$ Positive deviation (surplus) for community i, experience level m, in time period t.

$g^-(t) \equiv$ Negative deviation (shortfall) from total officer inventory limit in period t.

With these definitions in hand we now proceed to construct the relevant constraints. First we express inventories in terms of beginning inventories:

$$(1.1) \qquad y_{ijk}(t) = S^t_{ij}(k-t)I^o_{ij}(k-t) \qquad \text{for } 2 \leq t \leq k.$$

Note that the inventories $y_{ijk}(t)$ are immediately determined for $2 \leq t \leq k$ by the relation (1.1). Next, for $t > k$, these inventories depend on subsequent accessions, so that

$$(1.2) \qquad y_{ijk}(t) = S^k_{ij}(0)x_{ij}(t-k) \qquad \text{for } t > k$$

The relation between officer inventories and goals, by community and experience level, are expressed as:

$$(1.3)\qquad \sum_{j=1}^{J} \sum_{k=\ell_i(m)}^{u_i(m)} y_{ijk}(t) + g^-_{im}(t) - g^+_{im}(t) = G_{im}(t)$$

which, as may be noted, defines a set of "goal constraints."[1]

The limitations on total officer inventories $E(t)$ are expressed by

$$(1.4)\qquad \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} y_{ijk}(t) + g^-(t) = E(t).$$

Observe that this $E(t)$ value is not to be exceeded.

Pay and allowance budget limits are expressed by:

$$(1.5)\qquad \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} b_{ijk}(t) y_{ijk}(t) \leq B(t)$$

where the $b_{ijk}(t)$ refer to the projected funds flows which are pertinent to the pay and allowance budget limits $B(t)$ in each period.

We now address issues connected with constraints on the officer accessions from various sources to various warfare communities. First, the total number of officer accessions may be limited in each time period via:

$$(1.6)\qquad \sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij}(t) \leq P(t).$$

[1] See [3].

Each community may have training capacity limits for newly commissioned officers, expressed by:

$$(1.7)\quad \sum_{j=1}^{J} x_{ij}(t) \leq R_i(t).$$

The commissioning sources will usually have acceptable upper and lower operating limits:

$$(1.8)\qquad Q_j(t) \leq \sum_{i=1}^{I} x_{ij}(t) \leq P_j(t).$$

Finally, we allow for possible upper and lower bounds upon the acceptable distribution of newly commissioned officers from each source to each community:

$$(1.9)\qquad Q_{ij}(t) \leq x_{ij}(t) \leq P_{ij}(t).$$

It may also be necessary to provide for a distribution of newly commissioned officers from each source, to each community, that does not fluctuate radically from period to period. There are several possible methods for reducing such fluctuations. One would involve penalty factors using quadratic terms or other nonlinear convex functions in the objective function. Another approach, which we have chosen here, would proceed via constraints that limit the proportional changes allowed for the period-to-period inputs planned for each community and the period-to-period outputs from each source. The relations we use for this purpose are expressed by:

$$(1.10.1)\ \alpha(t) \sum_{j=1}^{J} x_{ij}(t) \leq \sum_{j=1}^{J} x_{ij}\ (t+1) \leq \beta(t) \sum_{j=1}^{J} x_{ij}(t),$$

for the accessions to community i and

$$(1.10.2)\quad \gamma(t) \sum_{i=1}^{I} x_{ij}(t) \leq \sum_{i=1}^{I} x_{ij}(t+1) \leq \delta(t) \sum_{i=1}^{I} x_{ij}(t)$$

for the outputs from source j. The $\alpha(t)$, $\beta(t)$, $\gamma(t)$, $\delta(t)$ are suitably chosen constants that represent minimal and maximal proportions of change allowed between adjacent time periods. These proportions may vary over time, of course, to reflect conditions in which near term plans may be less flexible than later ones.

Finally, we impose the condition that our variables are to be non-negative, viz.,

$$(1.11)\qquad x_{ij}(t) \geq 0,\ g^-_{im}(t) \geq 0,\ g^+_{im}(t) \geq 0,\ g^-(t) \geq 0.$$

For this model we set our objective to be minimization of:

$$(1.12)\qquad \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{m=1}^{M} (w^+_{im}(t)g^+_{im}(t)+w^-_{im}(t)g^-_{im}(t)) + \sum_{t=1}^{T} w^-(t)g^-(t)$$

which is to say that we seek an officer accession and distribution plan that minimizes weighted deviations from officer strength goals, subject to the above constraints. In other words, our model is of a goal-programming variety.[1/]

4. EXAMPLE

This completes our formal model development. To illustrate its use we now present an example which highlights certain features and omits others. Thus we confine this example to Unrestricted Line (URL) officers and omit the financial constraints - but, we observe that the results of this example can provide the impact on budgets if desired by substituting the resulting $y_{ijk}(t)$ values in (1.5) to study the funds-flow consequences of these plans. In this way a match may be a match may be effected with the funds requirements of other Navy programs in each relevant period as an aid to budgetary planning.

[1/] See [3]. Other manpower planning models of a goal programming variety are treated extensively in [6] and [17]. See also [4].

This example considers only the first ten years of commissioned service which, from a practical standpoint, includes the "choke points" for most warfare communities. A "choke point" represents a period in the career path of a community where inventories fall short of requirements for critical assignments.

There is a need to consider different horizons so that end effects can be ascertained and undesirable postures avoided. There are various ways of accomplishing this.[1/] In the present example we extend the model horizon period to twenty years so that accession for the first ten years will be fully accounted for through ten years of commissioned service.

The following warfare communities are included in our example: Surface, submarine, aviation (pilots), and naval flight officers. Table 1 describes the officer commissioning programs that are used.[2/]

The actual Navy data used in this example were modified and treated in ways that would make them more suited to our illustrative uses. They are nevertheless representative of the kinds of actual uses for which the model is intended. The voluminous character of these data precludes its reproduction here and, in fact, even the outputs require various summary devices to enable us to depict results of applying the above model to these data within the compass of this article. We illustrate via Figures 1 and 2.

Figure 1, which provides an example of inventory and requirements for the submarine community in the tenth planning year, may be interpreted as follows. The unshaded portions of the bar graphs represent projected officer inventories as determined by the model for this warfare community. The shaded portions represent operational requirements. The numbers within each bar refer to the inventories while the numbers on the outside refer to deviations (plus or minus) between these inventories and the requirements.

1/ See for instance the use of "horizon posture constraints" as described in [2].

2/ These programs represent the bulk of the Navy's commissioning sources.

TABLE 1

Officer Commissioning Programs

Title	Description
USNA	U.S. Naval Academy
NROTC (S)	Naval Reserve Officer Training Corps regular (scholarship) program
NROTC (C)	Naval Reserve Office Training Corps contract (non-scholarship) program
OCS	Officer Candidate School
NESEP	Navy Enlisted Scientific Education Program*
AOC	Aviation Office Candidate program (pilots)
NFOC	Naval Flight Officer Candidate program (non pilots)
AVROC	Aviation Reserve Officer Candidate program

*Being phased out. See the following discussion of Figures 1 and 2.

Because in some cases the requirements exceed inventories (and vice versa) we have further distinguished the two by terminating the total requirements with a dotted line for its portion of the bar while total inventory is terminated with a solid line. Note that the first two years of service represent training for the subsequent years and hence no specific requirements are stated for them. In other words, these inventories are implicitly determined by reference to the goals for subsequent service.

Evidently the model accumulates excess inventories in lower YCS categories to meet the high priority requirements for experienced officers, inter alia because the deviations in the latter categories are accorded higher weights in the functional being minimized. The officers who are surplus to community requirements are rotated through operational staff and other general warfare billets during these periods in order to fill total Navy requirements.

The NESEP commissioning program[1/] has been phased out, but it has been a large contributor to submarine officer requirements in the 7-10 year YCS range.[2/] In view of the difficulties encountered in meeting these requirements in Figure 1, we next utilize the model to explore the consequences of continuing NESEP at its traditional levels.

[1/] See Table 1.

[2/] Study of the effects of phasing out the program formed a part of the tests for this model which has now been adopted by the Navy as one part of its approach to manpower planning.

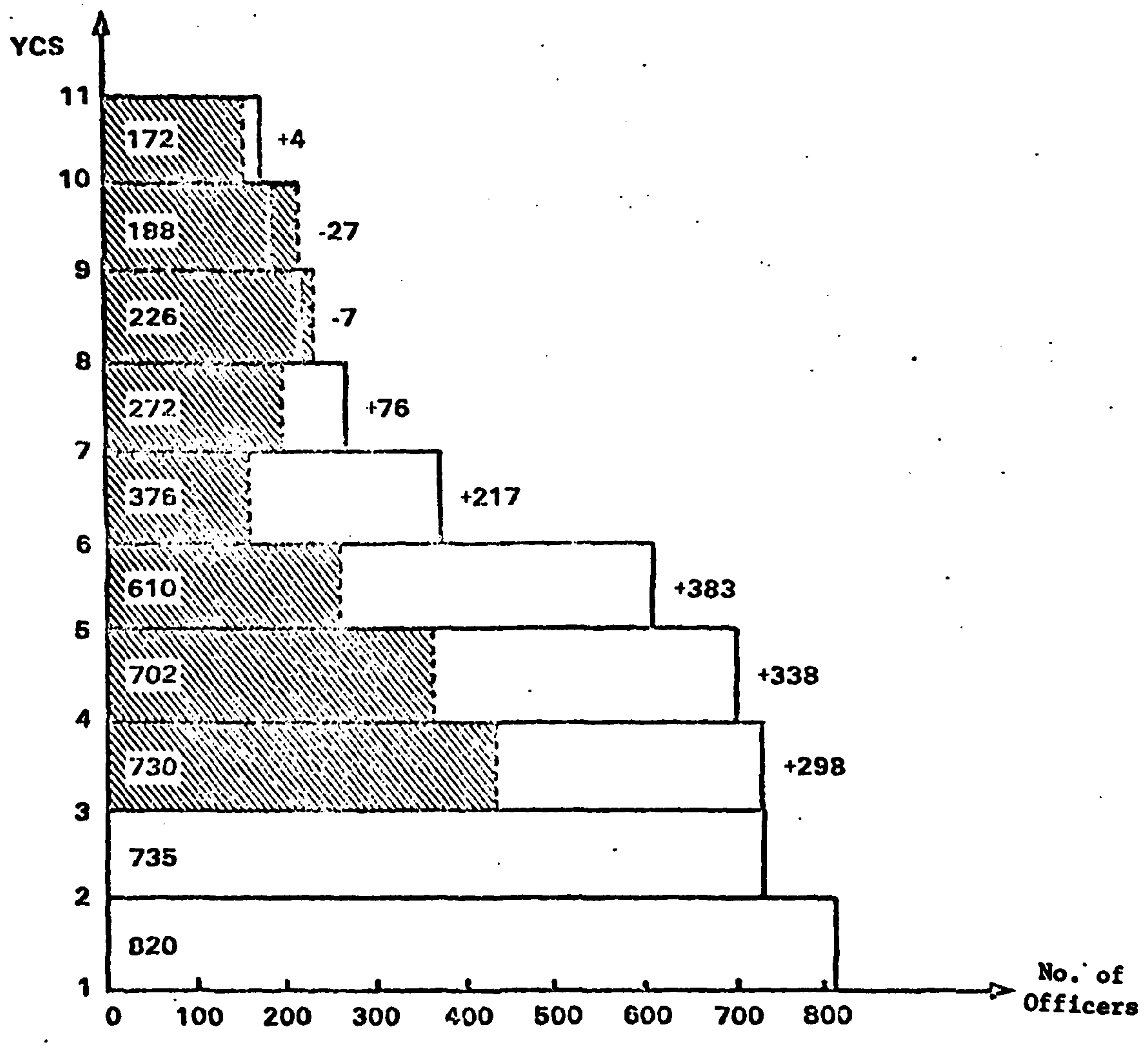

Figure 1. Submarine community inventory and requirements, NESEP omitted.

Figure 2 represents the results of such an exploration. Observe that the program of this Figure comes much closer to meeting the high-priority 7-10 year YCS category requirements. Furthermore, it accomplishes this in a way that requires much lower accession levels, and the goal deviations are also smaller in all of the other categories as well. This results from the much lower attrition rates of the NESEP accessions for the first ten years. NESEP accessions commonly have accumulated some period of service prior to commissioning, however, so that many of these persons are likely to retire on completion of ten years of commissioned service. The advantages of these retention and subsequent retirement patterns need to be weighted alongside other considerations besides those covered in this illustrative example, of course, and the model may also be extended and applied for these purposes as well.

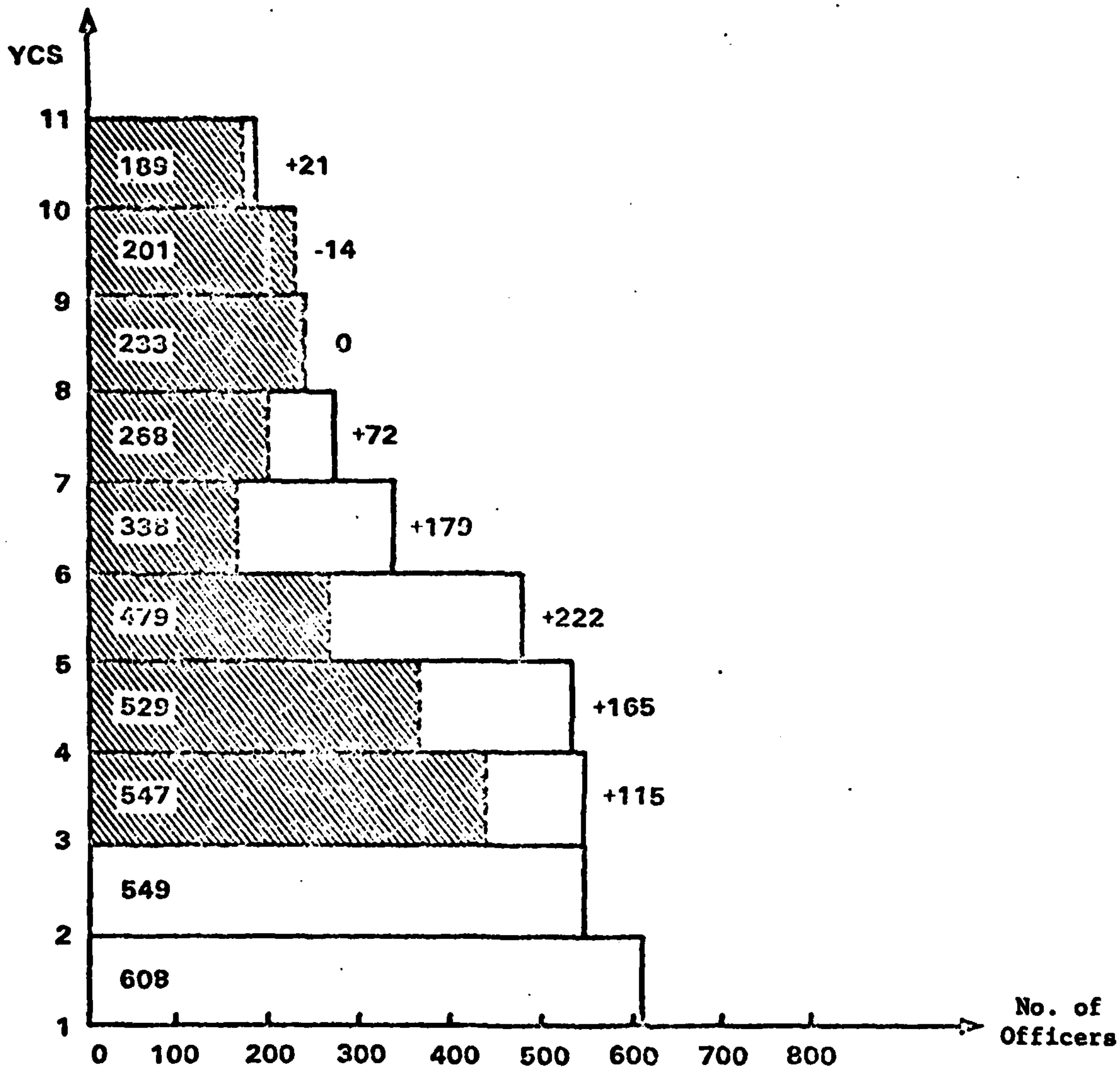

Figure 2. Submarine community inventory and requirements, NESEP retained.

5. IMPLEMENTATION

The model discussed and illustrated above has been developed and implemented in coordination with the Officer Program Implementation Branch of the U.S. Navy Deputy Chief of Naval Operations (Manpower, Personnel, and Training). It will now be used on a regular basis during the annual accession planning process and it will, of course, also be available for other uses as needed for policy analysis.

Previously accession planning was based upon individual warfare community accession studies that were used as elements for guiding the development of an overall plan. Some give and take was needed in moving from the details of these individual warfare community plans into an overall plan. The present model augments these planning procedures by allowing systematic consideration of community requirements in full detail while at some time it provides a new capability for coordinated development of an overall officer accession plan. It has added flexibility to the planning process by its access to readily available computer codes and routines of linear programming and goal programming varieties. It has also provided new capabilities for evaluating tradeoffs, including capacity or policy restrictions that bear on alternate allocations of limited accession resources.

6. EXTENSIONS

The example that has been discussed illustrates several uses of the model. The central application of the model is to determine the operating levels of various commissioning sources and the distribution of officers produced by each source to the different warfare communities, based upon community requirements. This application provides an accession plan that may be used in the actual planning process. Another product of this application is the projection of community inventories and comparison with community requirements so that, as in the preceding Figures, the impact of the plan developed by the model can easily be seen. These outputs of the model can also be used to evaluate accession policies represented by source operating and distribution limits. For instance, it was seen in our illustrative example that submarine choke point requirements could not be met without relaxing the distribution limits for the case represented by Figure 1. The consequences of eliminating a commissioning source were also seen in the comparison of Figures 1 and 2.

The model can also be used to suggest or evaluate changes in the community requirements structures. Often the arrangement of tours in a career path is influenced by community career planning considerations, as experience requirements for operational billets may in fact be more flexible than a specific requirements plan indicates. Outputs of the model indicate when large discrepancies between inventories and a particular set of requirements are likely to develop. The model may then be used to guide the choice of a different requirement structure.

The question of how to allocate excess officers in each community to overall Navy requirements for general warfare specific billets has been addressed in different ways during development of the model. A final resolution of this issue would require further model developments but in the meantime the present model can be used by overall accession planners to evaluate tradeoffs between requirements in the various officer communities. In the example of Figures 1 and 2, high priority was placed upon meeting submarine community choke point requirements, which were filled at the expense of meeting requirements in other communities. Stated accession requirements by the various community accession planners often exceed total resources and the model provides a new opportunity to evaluate accession tradeoffs between communities in a systematic way.

The studies to date have involved linear programming problems of approximately 700 rows and some 1,500 to 2,000 variables. This size reflects a reduction achieved by eliminating (1.1) and (1.2) as explicit expressions in the model and instead using the resulting $y_{ijk}(t)$ in the same manner that we previously indicated for (1.5).

General purpose computer codes that are already available are more than adequate to deal with problems of this size. Further elaboration or extensions of the model such as we have been indicating, however, will sooner or later encounter computational problems. But then an examination of the "goal programming/accessions model" that we have provided will show that it already possesses a considerable amount of network (or capacitated distribution) model structure. Exploitation of this structure should therefore provide access to the high speed network codes for dealing with large-scale problems that are already available. Examples of such an approach may be seen in the goal-arc formulations described in [4] and [5], as well as [18].

The route to exploiting these features of our "goal programming/accessions model" may be briefly set forth in the following manner. The variables $x_{ij}(t)$ in constraints (1.6)-(1.9) evidently have a capacitated network structure.[1/] The goal constraints (1.3) and (1.4) could be replaced by nonlinear expressions of goal deviations in the functional. Other parts of the model involve coupling constraints to handle the interactions between the flows. It may be possible to express the coupling conditions through additional nonlinear terms in the functional and then possibly reduce the whole problem back to a larger capacitated network problem. Although the budget constraints (1.5) would present further problems the usages indicated in the present article present one possible treatment by laying them aside as an aid to overall budgetary planning.

[1/] See Charnes and Klingman [8] and Charnes, Glover and Klingman [7].

without such reductions, however, especially efficient linear programming codes have been devised which take heavy advantage of even partial network structure.[1] Further, codes are now in the process of development which efficiently compute network structures with nonlinear convex functionals.

Although our model has been oriented toward a special class of situations, it is clear that many analogous situations exist in manpower planning problems. Generally speaking an approach like ours will be applicable whenever extensive experience and preparatory training are required at higher levels while entry must be effected from lower levels. Official "promotion-from-within" policies must necessarily encounter such phenomena in cases like manpower planning for scientific-professional R & D labs. Other such situations in practice may also be envisioned and this should also help to justify the further research that we have just indicated for exploiting more fully the network features of our goal programming/accessions planning model.

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[1] Cf. [10].

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13. ABSTRACT

A goal programming model for planning officer accessions to the U.S. Navy from various commissioning sources is developed and described. Present and future requirements for different career specialty areas in the Navy are considered in terms of years of commissioned service and related to various "choke points" where inventories fall short of requirements in officer force structure. An illustration of the use of this model is provided which involves assessments of the effects of phasing out one commissioning source. Other uses and possible further extensions are also indicated for this model, which now forms a part of the Navy's manpower planning procedures.

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
U.S. Navy Officer Accessions						
Warfare Communities						
Officer Accession Sources						
Goal Programming						
Markoff Process						
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